Synopsis for Ph.D. Thesis

"Seismic Imaging of Crust and Upper Mantle Structure of Intraplate Earthquake Source Region Killari, Maharashtra, India"

Submitted to

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Abstract:

In the present study a 10 broadband seismic station network is established adjoining area of Killari spanning over 200 x 200 km^2 . This data will be used in understanding the crustal and Upper Mantle structure beneath the intraplate earthquake source region of Killari. The proposed study will be useful in understanding the continental crust, upper mantle structure and its evolution. As this region has witnessed one of the major intraplate earthquake, it is imperative to study and understand the structure of this region. Receiver Function method will be enabling to understand the structure beneath each seismic station. The converted seismic phases and Seismic Tomography will be useful to interpret the 3 D structural configuration of the region based on the relative wave velocities of teleseismic waves recorded in the network. The local seismicity recorded in the network during the proposed study will help us in understanding the active faults and its seismicity in this region.

Keywords: Earthquake, Seismology, Receiver Function, Seismic Tomography, South East Deccan Volcanic Province (SEDVP).

Introduction:

The crustal structure is directly accessible to a depth of only a few kilometers in boreholes and mines. Geophysical methods are used to estimate the characteristics of deep crustal and upper mantle structures of the Earth and the in-depth structure of the Killari and adjoining regions (SEDVP) has been less studied using geophysical methods at this scale.

The focus of the present study would be on evaluating the crustal and upper mantle structure of the Killari and adjoining regions (SEDVP) using the Receiver Function technique and Seismic Tomography.

In the present work, an 08 Broadband seismic stations network is established in the adjoining area of Killari spanning 200 x 200 km^2 (Figure 1) operated by S.R.T.M. University, Nanded and two stations of the National Center for Seismology, New Delhi. The present study is funded by RUSA Maharashtra. We intend to do a comprehensive study to understand the crustal and upper mantle properties of the intraplate seismic zone. This study will be useful to understand the intraplate seismicity of Killari and adjoining regions (SEDVP).

Geology of Study Area:

Deccan Volcanic Province (DVP) is the largest magmatic region with an area of 500,000 km^2 (Krishnan 1960) covering the central part of India including the state of Maharashtra, Madhya Pradesh and Gujarat. Nearly 65 million years (Ma) ago (Verma and Khosla, 2019) while northward drift of Indian plate passing over the Reunion hotspot (Morgan, 1972; White and McKenzie, 1989) volcanic eruption of Deccan Basalt taken place (Chatterjee and Bajpai, 2016), this volcanic activity consists of dominant basaltic lava. Geomorphological studies indicate that the river pattern of peninsular India flows from west to east following natural slopes (Kale 2002). This complex structure is associated with a high gravity anomaly which indicates that at a certain depth a dense plutonic body is present (Tiwari et al., 2001).

The thickness of DVP is highest at the western margin and as we move in the direction of the east, the thickness decreases (Patro and Sarma, 2007) and the thickness of the Deccan Trap towards the East of around 196 m in Nanded and further east the Archean Granites are exposed near Kinwat region of Maharashtra. To generate such huge amounts of basaltic melt, generally a

huge thermal anomaly is required and mantle plume models are invoked (White and McKenzie 1989). There are two possible theories regarding how a plume interacts with the Continental Lithosphere; one is the active mantle hypothesis of Morgan (1971, 1981) wherein it is considered that Mantle plumes drive plates and initiates continental breakup by doming and cracking the continents and pushing the continents apart. The other is a passive model where plume does not result in breaking up continents except for the fact that it result in rapid out-pouring huge amounts of flood basaltic magma. It is speculated that the Reunion Hotspot was the source of thermal energy in generating huge volumes of flood basalts when Indian plate passed over it during Cretaceous-Tertiary times (Morgan, 1981; Richards et al., 1989; Campbell & Griffiths, 1990). The mantle plume model however is challenged by (Sheth 1999, Sheth et al., 2003) describing that the Continental Flood basalts have formed due to rifting based on geochemistry and geochronology and Petrology and does not necessarily need a plume model to support the generation of Deccan Basalts.

South East Deccan Volcanic Province (SEDVP) mainly located in Maharashtra, with some of the exposures extending into parts of Karnataka and Telengana (Kaplay et al., 2017). The SEDVP is a major area of scientific importance for studying the 3D velocity model, the seismicity of this region and the deep velocity structure of the intraplate seismic source region. To study these features, understanding the evolution of SEDVP requires the crust and upper part mantle 3D velocity structure. The study of crustal and upper mantle structure becomes significant to derive the Seismo-tectonic map of SEDVP region.

The velocities of P and S-waves in the lower crust and upper crust are higher in the Deccan region than in the South Indian shield (Mohan et al., 1997, Iyer et al., 1989). From the seismic data analysis (Ramesh et al., 1993) inferred that the hypothesized causative plume head is absent beneath the Deccan trap.

Review of Literature:

Some of the geophysical studies are carried out to find the nature of the subsurface topography and crustal structure of the DVP region. The Deep Seismic Sounding profiles (DSS I and DSS II) (Kaila et al., 1981a, 1981b) were used to find sub-surface crustal structure which provided that the Moho depth variation from 36 to 40 km beneath east of western Ghat. The

Moho depth decreases to 30 km near the coast of the Konkan plain (Tiwari et al., 2001). From the seismic records of travel time and relative amplitude models have been discovered that low-velocity layers are present in the crust and upper mantle of the western part of the DVP region (Mandal, 2019).

Other geophysical methods such as Deep electrical sounding and Magnetotelluric (MT) soundings revealed that the thickness of trap varies from 220 to 1200 m from eastern to western region (Bhaskar Rao et al., 1995) of Latur earthquake epicentral area and the surrounding the Kurduwadi gravity low (Sarma et al., 1994) which is having a trap thickness of 300 - 500 m and seismological studies suggested that the low-velocity layer of fluid filled zone present at the similar depth (Gupta et al., 1996). The thermodynamics study suggests that the heat flow values range from 34 to 48 mW/m^2 and from the heat generation and heat flow, 38 km thick crust is present in this region (Roy and Rao, 2000). Samples collected in the drill hole at the epicentral area of the Killari earthquake show an average bulk density of lava flows of 2.65 gm/cm^3 measured in a dry state and 2.72 gm/cm^3 in a wet state. The density of granite-gneiss basement encountered in the borehole is 2.74 gm/cm^3 (Pandey et al., 1998). The Archean granite is present at the basement of DVP which is confirmed from the drill hole measurements (Zachariah, 1998).

There were two major intraplate earthquakes in the DVP region. One is the Koyna earthquake of magnitude 6.1 in 1967 and the second one, the Killari earthquake of magnitude Mw 6.1 in 1993, has drawn attention to the subsurface structure and tectonics of the DVP region. The seismic activity of the Koyna earthquake is attributed to be caused by a reservoir-induced seismicity (Gupta, 1992) whereas the Killari earthquake is thought to be due to the reactivation of the weak zone. (Gupta et al., 1996; Rajendran et al., 1996).

The gravity data show two distinct sources of long-wavelength gravity, the 'Koyna Low' and the 'Kurduwadi Low' observed on the DVP. The Koyana low is mainly due to isostatic compensation, manifested as crustal thickening up to 40 km with a lower density (3.2 g/cm3) upper mantle and The Kurduwadi low appears to be shallow and is mainly due to deposition of low-density material, such as a Granitic body with a fracture/shear zone (Tiwari et al., 2001) suggesting plausible interaction of Indian lithosphere rifting of Reunion hotspot on the west Coast of India.

Radial and tangential receiver function studies in the Nanded region showed that the depth of the Moho is about 36 ± 2 km and the low velocity near the surface layer is significant with a 2 km thin crust-mantle transition zone (Rai et al., 2003). (Kumar, et al., 2000) study revealed that the crustal thickness of DVP is about 34 - 40 km and the EDC is about 32 -34 km; this suggests that the crustal thickness is higher at DVP than at EDC. The crustal composition of the DVP is intermediate - mafic where as the EDC is Felsic - intermediate. The crust beneath the DVP is displaying a gradient Moho with the presence of magmatic material, while below the EDC, the Moho is sharp and lacks an under plated layer at the crust-mantle boundary (CMB).

Objectives of Research:

The objective of this study is to delineate the properties of the crustal and upper mantle structure and therefore to understand the evolution of the South East Deccan Volcanic Province (SEDVP).

- **To Study the structure of the continental crust and the upper mantle structure of the SEDVP and provide the evolution of the SEDVP.**
- **To find the continental crust and the upper mantle thickness and identifying the faults zones of the SEDVP region, if any.**

To address these problems, we have installed about 10 Broadband seismic stations near and adjoining areas of Killari, Maharashtra, India. The data will be analyzed for Teleseismic earthquake waveforms recorded at these stations for the crust and upper mantle signatures. Receiver function technique will be used to demarcate the crustal structure beneath the SEDVP. This technique is a powerful method for modeling the crustal and upper mantle structure from the converted phases to provide the shear structure and sub-surface rock composition of the SEDVP region.

Methodology to be adopted:

- Receiver Function Modeling
- Seismic Tomography

Receiver Function Modeling:

To find the crustal structure of the Deccan volcanic Province (DVP) region, travel time and amplitude of the converted P to S seismic waves from the earthquake sources occurring between the epicentral distances of 30°- 90° are used. In the explosive source methods as the geophone (Receiver) to source distance is large, wave travels horizontally large distance and produces significant lateral averaging of the velocity and hence sharper and smaller anomalies may be missed. To avoid these 3 – component digital seismograph technique is used which can record Teleseismic waveforms (Ammon 1991).

Earthquakes are selected of magnitude more than 5.5 and the epicentral distance is 30°-90°. This range is chosen to avoid multiples at distances less than 30° and triplication at distances greater than 90°. After marking the P phase, the seismic trace is cut for 150 sec, including 30 sec before the P mark and 120 sec after the P mark, then applying the Butterworth high -pass filter having a corner frequency of 0.02 Hz (Ammon et al., 1990, Ammon 1991).

For the estimation of Moho depth, the Receiver Function (RF) method utilizes the splitting of P-to-S and S-to-P converted phases from velocity discontinuities in the crust and upper mantle to characterize the depth and velocity structure of the discontinuities. These converted phases of P-to-S and S-to-P are most clearly observed when the original three-component seismograms are source normalized to form RFs. The P-to-S conversions from the depth phase of d410 and d660 were recognized as P410s and P660s; these differences from Source (Earthquake) to the splitting parameters in the contribution of anisotropy in the lower mantle (Kong et.al., 2018).

Seismic Tomography:

Seismic tomography is the method that can be used to determine the characteristics of seismic waves generated from an explosive source or natural earthquake and also deduce the spatial distributions due to the variation in parameters recorded in the receiver. It applies to the travel time of body waves generated from an earthquake to find the subsurface image using Vp and Vs (P- and S-wave velocities) (Thurber et. al., 2007).

With the help of Seismic tomography method, it is possible to derive the parameters like Vp/Vs ratio, presence of mafic and felsic materials and their physical state (De Matteis et al.,

2008). To find the anisotropy of the propagation medium, seismic velocities and tomographic inversions are used, which can provide information about the discontinuities of spatial settings and regional stresses in the structures. The seismic tomography techniques were used for mapping the crustal and upper mantle velocity structures in the region using the travel time of P and S waves (Johnson et al., 2011; Johnson and Savage, 2012).

Importance of study:

International status

The globally spread flood basalts are the Siberian Traps, the Columbia River plateau of North America, the Deccan Traps of central India and large igneous provinces of Canada. The flood basalts are caused by the mechanism of continental rifting and decompression melting; they can be spread over a large area as a flood basalt province (Leitch et al., 2001). For the formation of such a flood basalt province, a huge thermal anomaly is necessary and mantle plume models are invoked (White and McKenzie 1989, Campbell and Griffiths 1990). The Morgan 1971 and 1981 theories revealed that the interaction of plumes with the continental lithosphere initiated cracking and break-up of continents, which resulted in separation of the continental blocks from each other. In the Cretaceous – Tertiary period, when the Indian plate passed over the Reunion Hotspot, it poured out huge amounts of flood basaltic magma, resulting in the formation of Deccan basalt (Morgan, 1981).

Extensive geophysical studies have been carried out to understand the subsurface structure and stress concentration mechanism in Intraplate earthquake regions like the New Madrid Seismic zone (Johnston 1996, Johnston and Schweig 1996), Swabian Jura, Southwest Germany (Turnovsky and Schneider 1982), Ghana (Talwani and Rajendran, 1991), Australia (Langston, 1987), Miramichi-Canada (Hasegawa, 1991; Talwani and Rajendran, 1991). The New Madrid Seismic Zone (NMSZ) and the Australian cratons were exhaustively studied using the Tomography and Receiver function technique. The NMSZ is associated with a local NE-SW trending low velocity anomaly in the lower crust and the upper mantle. In most of the intraplate scenarios, it is identified that the localized stress concentrations occur at old rifts, intersections of faults, or on the periphery of plutons. (Gangopadhyay and Talwani 2003).

National Status

In the Indian region, Intraplate earthquakes were observed like Latur earthquake in 1993 having magnitude Mw 6.3 (Rajendran et. al. 1996, Kayal et. al., 1996), Bhuj earthquake in 2001 having magnitude Mw 7.5 (Kayal et.al., 2002). The Latur region studied by (Sharma et. al., 1994) using Magnetotellurics (MT) soundings reflects the thickness of a trap around 300 – 400 m and shows that a conductor in a hypocentral zone that has intruded into the shallow upper crust. The orientation of the conductor is along the WNW–ESE direction. At the depth of 6–10 km, resistive upper crust is present.

The Latur earthquake foreshock and aftershock study revealed that the fault plane mechanism of the region is a reverse fault (Baumbach et. al., 1994) which reflects that the Latur region is under a compressional regime. The velocity model of the earthquake area revealed by local seismic tomography method (Kayal and Mukhopadhyay, 2002) the main shock of earthquake occurred in between of High Velocity Zone (HVZ) and Low Velocity Zone (LVZ) at the 6 km depth. As the maximum depth of free shocks and aftershocks were shallower than the main shocks representing the fault plane along the E–W trend (Mukhopadhyay et. al., 2002).

Significance of the study

The study region witnessed one of the deadliest intraplate earthquakes in 1993 with a casualty of more than 10,000. The studies carried out for these regions have been scanned only in some parts of the DVP region. The aftershock studies carried out at Latur have resolved only the top of 6 km because all the events were less than 6 km in focal depth. In addition, it is important to understand the crustal and upper mantle thickness and its depth in the region to understand the formation of the DVP.

The Receiver Function (RF) Technique and Teleseismic Seismic Tomography Method are well suited for the understanding of the crustal structure, characteristics of the upper mantle and the seismotectonic of the region. To understand the evolutionary mechanism of the Deccan Trap and to derive the seismotectonic character of the region. It is necessary to understand the 3D velocity structure of the crust and upper mantle structure of the DVP region.

Proposed work Plan:

1st year:

- Course work
- Literature survey
- Installation of Broadband Seismometer
- Data collection
- Preliminary data analysis

A review of published literature on Seismological study of Receiver Function Modeling; Seismic Tomography will be carried out.

2nd year: Data collection, analysis and processing of Preliminary results.

3rd year: Interpretation of preliminary results and finalization of the results, scientific papers and thesis writing.

- Interpretation of Data: Earthquake data analysis and interpretation of the data.
- Presentation in Seminars: At national and international level.
- Publication of research papers: In National and International Journals.
- Writing and Submission of Thesis: The thesis will be written after the interpretation of data and accomplishment of objectives will be submitted at the end of the third year.

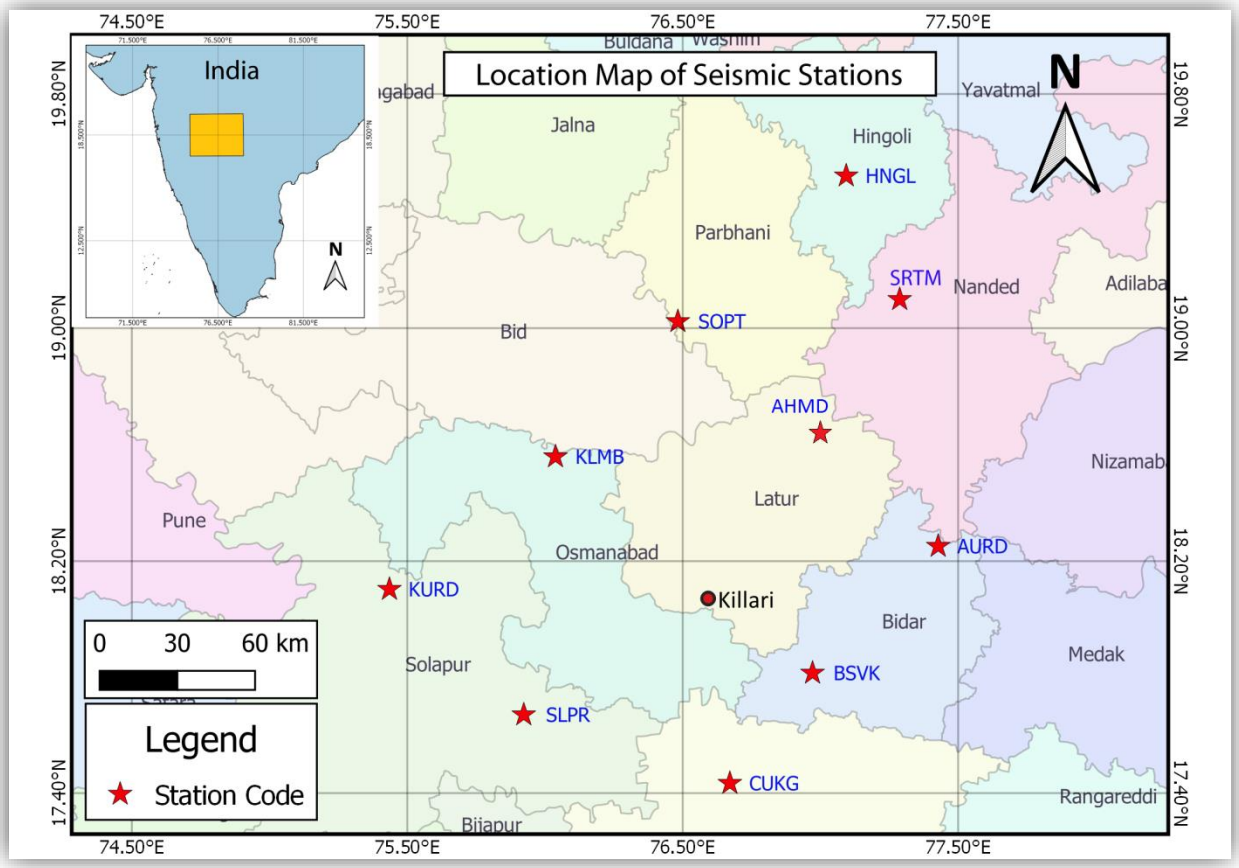

Figure 1: The study region showing the location of Seismic station near and adjoining area of Killari which can be used in the proposed work.

Sr. No.	Station Code	Station Name	Latitude	Longitude	Elevation (Meter)
01	AHMD	Ahmedpur	18.69557	76.94544	535
02	AURD	Aurad	18.25360	77.42765	487
03	BSVK	Basavakalyan	17.81447	76.97076	614
04	CUKG	Gulbarga	17.43422	76.67121	486
05	HING	Hingoli	19.65430	77.09431	413
06	KLMB	Kalamb	18.56274	76.03832	605
07	KURD	Kurduwadi	18.10283	75.43527	464
08	SLPR	Solapur	17.67031	75.92297	403
09	SOPT	Sonpeth	19.02896	76.47590	328
10	SRTM	Nanded	19.09806	77.28790	316

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